

# Evaluation of Uniformity Coefficients for Sprinkler Irrigation System under Traditional and Looped Network Field Conditions

Khalid Adel Abdulrazzaq  
Engineering College  
University of Baghdad

Udai Adnain Jahad  
Engineering College  
University of Babylon

## Abstract

The efficiency of the sprinklers are connected with the values of coefficients of uniformity, the higher value of such coefficient means best system efficiency. In fact, the coefficient of uniformity expresses the uniformity of water distribution. Christiansen's uniformity coefficient seems to be the most popular uniformity coefficient used by many researchers on the global scale. This study proposed a new method of connection to improve the uniformity coefficient, and this is done by redistribute the pressures through the sprinkler system. The traditional system includes dead (end) laterals, and mostly the pressure is reduced as the distance between the source and the sprinkler is increased. Therefore, in this research the researchers connect the laterals, so, the sprinkler system is work as a looped network, to get high pressure at the ends, which lead to improve the sprinklers duty which lead to raise the system efficiency. A field data is measured from a sprinkler system at Khagan Village in Babylon Governorate, 30:15:15 E, 44:40:30 N in the middle of Iraq, in the period between November and December at 2011. To check the field results, EPANET software version 13 is adopted for the theoretical calculations, also, analogue approach is adopted to simulate the field sprinkler system for both, traditional and proposed (looped) system. In Analogue approach, an electrical board is constructed to simulate the field, where, the thermal wires represent the laterals, while, the resistances are simulate the sprinklers. A relationship has been concluded through the derived equation between the sprinklers discharge and resistance voltage. A new relative equation has been concluded by comparing both equations that are derived from the field. The results of the field, theoretical, and analogue results prove that there is a great proximately among pressure results from the proposed connections (looped network) as compared with the well-known traditional method. The mean performance of the uniformity coefficient are raised by(7.59%) for practically looped network, and raised by(11.45%) for theoretically looped network.

## المخلص

ان كفاءة المرشات مرتبطة بقيم معاملات الانتظامية في التوزيع، وكلما ارتفعت هذه المعاملات كلما اشرت على كفاءة منظومة الري بالرش. ومن المعلوم ان هنالك العديد من معاملات الانتظامية المقترحة من قبل الباحثين واكثرها شيوعا هو معامل الانتظامية الخاص بـ (كرستيان) على النطاق العالمي. هذه الدراسة اقترحت طريقة ربط جديده لتحسين معمل الانتظامية من خلال اعادة توزيع الضغوط داخل شبكة الري بالرش. النظم التقليدية تعتمد مبدأ النهايات المغلقة لخطوط المرشات (الخطوط الموزعة)، وهذا يعني انخفاضاً في قيم الضغوط للمرشات كلما ابتعدنا عن مصدر التجهيز (الضغط). في هذا البحث، تم ربط النهايات لتعمل منظومة الري بالرش كوحدة واحدة بحلقه مغلقة (حلقية) لتحسين قيم الضغوط داخل المرشات وبالتالي لرفع معاملات الانتظامية. تم جمع البيانات الحقلية لنظام ري بالرش ثابت في الحقل الذي يقع في قرية خيكان ضمن محافظة بابل. للتأكد من البيانات الحقلية فقد تم الرجوع الى برنامج جاهز (EPANET) لتمثيل نظام الري بالرش للحقل وللحالتين، التقليدية والمقترحة. كذلك تم عمل لوحة كهربائية مشابهة لشبكة الري بالرش في الحقل، حيث تم استخدام اسلاك حرارية لتمثيل الموزعات والمقاومات لتمثيل المرشات وبذلك تم ايجاد معادله نسبيه تربط بين الحقل واللوحه الكهربائيه تصريف المرشة ومعادلة فرق الجهد في المقاومة. ومن خلال مقارنة النتائج الحقلية والنتائج النظرية وكذلك محور المحاكاة الكهربائي تبين ان الحالة المقترحة (الحلقية) افضل من النظم التقليدية حيث اظهرت النتائج بأن معدل التحسن في معامل الانتظامية لحالة التوزيع المقترحة في الحقل كان بحدود ٧,٥٩% في حين كانت ١١,٤٥% لحالة الحسابات النظرية.

## 1-Introduction

In the sprinkler method of irrigation, water is sprayed into the air and allowed to fall on the ground surface somewhat resembling rainfall. The spray is developed by the flow

of water under pressure through small orifices or nozzles. The pressure is usually obtained by pumping. With careful selection of nozzle sizes, operating pressure and sprinkler spacing the amount of irrigation water required to refill the crop root zone can be applied nearly uniform at the rate to suit the infiltration rate of soil. The uniformity of water application in a sprinkler irrigation system is an important aspect of the system performance (Solomon 1979). The performance of a sprinkler irrigation system is often evaluated based on water uniformity coefficients collected in an array of measuring devices (i. e., rain-gauge) (Topak et al. 2005). Such system requires a minimum value of uniformity to be considered as acceptable by the end users. Keller and Bliesner (1990) classified the irrigation uniformity in solid set systems as “low” when the Christiansen’s coefficient of uniformity was below 84%. A sprinkler water distribution pattern depends on the system design parameters such as: the sprinkler spacing, operating pressure, nozzle diameter, and environmental variables such as: wind speed and direction (Keller & Bliesner 1990). Several authors have reported the wind to be the main environmental variable affecting the sprinkler performance (Solomon 1979; Kincaid et al. 1996; Dechmi et al. 2003). The frequency distribution of the applied water can be assumed as normal and uniform functions (Anyoji & Wu 1994; Mantovani et al. 1995; Li 1998). The sprinkler irrigation distribution patterns have been characterized by various statistical uniformity coefficients (Karmeli 1978) and various coefficients of uniformity (CUs) have been developed over the past decades (Al-Ghobari 2006). Christiansen’s coefficient of uniformity (Christiansen 1942) was first used to introduce a uniformity coefficient to the sprinkler system (Karmeli 1978). The coefficient is presently widely used by researches on the global scale and has been applied as a proven criterion to define water distribution uniformity (Karmeli 1978; Topak *et al.* 2005). The coefficient is derived from rain-gauge data based on the assumption that the rain-gauge represent the same area and is a measure of absolute difference from the mean divided by the mean:

$$CU=100 \times \left\{ 1 - \frac{\sum_{i=1}^n X_i^2 - n \mu^2}{\sum_{i=1}^n X_i^2} \right\} \dots\dots\dots 1$$

where:

*n* – Number of the depth measurements of the water applied, each representing an equal irrigated area

*X<sub>i</sub>* – measured application depth (L)

*μ* – Mean application depths of (L)

CU– coefficient of uniformity (%)

When the CU value is approximately 70% or higher, the approximation depths from a rain-gauge evaluation tend to follow a normal distribution. In this case, when the mean application depth, *μ*, is equal to the required net application depth, *d<sub>n</sub>*, 50% of the irrigated area will be under-irrigated while the remaining 50% will be over-irrigated (or “adequately irrigated”). This is due to the fact that the normal distribution is symmetrical about the mean value (Merkley 2001).

(Wilcox and Swailes 1947; Aarsalan FfarRyabi 2010) used the same method used by Christiansen (1942), except that they used squares of the deviations from the mean instead of the deviations themselves. Their proposed equation is as follows:

$$\frac{\sigma}{\mu} U = 100 \times (1 - \dots) \dots\dots\dots 2$$

where:

- U – uniformity coefficient (%)
- σ – standard deviation of total depths of water (L)
- μ – mean application depth (L)

The coefficients of uniformity obtained in this manner are not as high as those in which the deviations from the mean are used such as in Christiansen’s equation.

Hart and Reynolds (1965) proposed “distribution efficiency”, *DEpa*, a value based on numerical integrations of the normal distribution function while *DEpa* is determined by first selecting a target *CU* and a target “percent area adequately irrigated”, *Pa*, where  $50\% \leq Pa < 100\%$  (which is a logical range for *Pa*). Should the normal distribution be assumed  $70\% \leq CU < 100\%$ , and

$$\sum_{i=1}^n \frac{\sigma}{\mu} X_i - \mu = n \sigma \sqrt{\frac{1}{\pi}} \dots\dots\dots 3$$

where:

- σ – standard deviation of all depth measurements (L)

Substituting Eq. (3) into Eq. (1),

$$CU = 100 \times \left\{ 1 - \frac{0.798 \sigma}{\mu} \right\} \dots\dots\dots 4$$

Criddle *et al.* (1956) and Beale and Howell (1966) also used the concepts of the deviations of the mean, like Christiansen (1942); however, Criddle *et al.* (1956) limited their equation to the lowest quarter depths of water while Beale limited the equation to the highest ones. Criddle *et al.* (1956) proposed their equation as follows:

$$CU = 100 \times \left\{ 1 - \frac{\sum_{i=1}^{\frac{n}{4}} X_i - \mu \frac{n}{4}}{\mu \times \frac{n}{4}} \right\} \dots\dots\dots 5$$

Beale and Howell (1966) also proposed an equation as follows:

$$CU = 100 \times \left\{ 1 - \frac{\sum_{i=1+0.75n}^n X_i - \mu \frac{n}{4}}{\mu \times \frac{n}{4}} \right\} \dots\dots\dots 6$$

Karmeli (1978) reported that the uniform distribution was an acceptable form to represent the sprinkler water distribution for stationary systems. He expressed the coefficient of uniformity as:

$$CU = 100 [1 - 0.5(X_{max} - \mu)] \dots\dots\dots 7$$

This equation is only valid for the values of *CU* higher than 50%.

Benami and Hore (1964) introduced their uniformity coefficient as “A” coefficient. Their equation is as follows:

$$A = 166 \left( \frac{2T_1b + D_1b M_1b}{2T_1a + D_1a M_1a} \right) \{ N_b \} \dots\dots\dots 8$$

**(2T<sub>1b</sub> + D<sub>1b</sub> M<sub>1b</sub>)/(2T<sub>1a</sub> + D<sub>1a</sub> M<sub>1a</sub>)} {N<sub>b</sub>**

Where:

- A– Uniformity coefficient (%)

$M_a, M_b$  – means of the measured application depths which are greater and smaller than the overall mean application depths (L), respectively

$N_a, N_b$  – numbers of the measured application depths which are greater and smaller than the overall mean application depths, respectively

$T_a, T_b$  – sums of the measured application depths which are greater and smaller than  $M_a$  and  $M_b$  (L), respectively

$D_a, D_b$  – differences between the numbers of the measured application depths which are greater and smaller than  $M_a$  and  $M_b$ , respectively

Merriam and Keller (1978) defined their “distribution uniformity coefficient” as follows:

$$CU=100 \times \left\{ \frac{D_{lq}}{\mu} \right\} \dots\dots\dots 9$$

where:

$DU$ – distribution uniformity (%)

$D_{lq}$  – mean of the lowest one-quarter of the measured depths (L)

Hawaiian Cane Society Specialists (cited by Merriam and Keller 1978) also proposed their uniformity coefficient as follows:

$$CU=100 \times \left\{ 1 - \left[ \frac{2}{\sqrt{\pi}} \right] \times \left[ \frac{\sigma}{\mu} \right] \right\} \dots\dots\dots 10$$

As stated previously, different researchers have used various concepts to express the coefficients of uniformity, hence the equations lead to different results in the expression of the distributed water uniformity in the same fields. The main objective of this study was to evaluate different uniformity coefficients proposed and investigate the effects of the field conditions on the end results obtained.

Magar et al. (2007) reported that under Indian conditions, the application efficiency of drip irrigation and sprinkler irrigation are 95% and 80% respectively whereas irrigation efficiency of major and medium irrigation projects is only 30% to 35%.

As a consequence, especially during periods of peak demand, the hydrant pressure head supplying the on-farm network may drop to unacceptable levels causing a severe reduction in irrigation performance resulting in farmers having to cut their supplies and postpone their irrigation (Rodriguez Diaz et al. 2007; Andre Daccache et al.2010).

## 2-Case Study

The main idea in the planning of the present work done in the field to study the pressure distribution and performance of the sprinklers on two proposed fixed-sprinkler irrigation networks. The first is a traditional dead-end and the second proposed looped network. The traditional and proposed networks were operated at the same circumstances.

## 3-Fixed Sprinkler

A fixed-sprinkler irrigation system has enough lateral pipe and sprinkler heads so that none of the laterals need to be moved for irrigation purposes after being placed in the field. Thus to irrigate the field the sprinklers only need to be cycled on and off, The three main types of fixed systems are those with solid-set portable hand-move laterals, buried or permanent laterals, and sequencing valve laterals. Most fixed sprinkler systems have small sprinklers spaced 10m to 27m apart, but some systems use small gun sprinklers spaced 33m to 54m apart.( National Engineering Handbook, 2005).

### 3-1 Sprinkler Head

Sprinkler head distribute water uniformly over the field without runoff or excessive loss due to deep percolation. Different types of sprinklers are available. They are either rotating or fixed type. The rotating type can be adapted for a wide range of application rates and spacing. They are effective with pressure of about 10 to 70 m head at the sprinkler. Pressures ranging from 16 to 40 m head are considered the most practical for most farmers. Fixed head sprinklers are commonly used to irrigate small lawns and gardens. Perforated lateral lines are sometimes used as sprinklers. They require less pressure than rotating sprinklers. They release more water per unit area than rotating sprinklers. Hence fixed head sprinklers are adaptable for soils with high intake rate. (National Engineering Handbook, 2005).

### 3-2 Spacing sprinklers

Used square pattern, with its equal sides running between four sprinkler locations, is used for irrigating areas that are square themselves, or have borders at 90° angles to each there, and that confine the design to that pattern. Although the square pattern is the weakest for proper coverage if not used carefully, enclosed areas often rule out the use of other patterns. The weakness in square spacing coverage is caused by the diagonal distance between sprinklers across the pattern from each other. When the sprinklers are spaced head-to-head along the sides of the square pattern, the distance between sprinklers in opposite corners of the pattern is over 70% spacing. This 70% diagonal stretch across the square pattern can leave a weak spot at the center. The wind may move the weak spot slightly away from the center and summer heat may make the weak spot quite large if it is a common climatic condition for the site. To minimize the effects of wind trouble when using the square pattern, closer spacing's (which require more sprinklers) are recommended, depending on the severity of the wind conditions. The recommendation on the chart for low or no wind is for 55% spacing. And on projects with higher winds, the spacing should be reduced as indicated below. ( National Engineering Handbook, 2005).

For sites with wind velocities of:	Use maximum spacings of:
0 to 3 mph (0 to 5 km/h)	55% of diameter
4 to 7 mph (6 to 11 km/h)	50% of diameter
8 to 12 mph (13 to 19 km/h)	45% of diameter

### 4- Field Work Layout:

The water source is AL-Zabar Stream in Khagan Village in Babylon Governorate, 30:15:15 E, 44:40:30 N in the middle of Iraq and the maximum pressure level is 60m head. Water is provided by using a pump give a head of 70m with flow rate(35 m<sup>3</sup>/min). Behind the pump there is a valve to regulate and control the main discharge and main pressure head in the main line. The main line is an aluminum pipe with 150mm diameter and 10m in length. The main pipe is divided into two manifold aluminum pipes each is 150mm in diameter and 10m long. From the manifold two laterals with valves at the head and end of each lateral. The lateral is aluminum pipe 100mm in diameter and 90m long. The spacing between two laterals is 30m; the ends of the laterals are looped together by an aluminum pipe 100mm in diameter. The main pressure gage is connected down-stream the pump and upstream the controlling and regulating valve on the main pipe. Other

pressure gages are connected at the head, middle, and the end of each lateral in the network. There are 13 gauges in total in the whole network. The traditional network is represented through the end valves enclosure while the proposed network is represented by opening the end valves and the sprinkler diameter is 4mm with discharge coefficient is 0.91 . Figure(1) shows the network at two cases, and the locations and numbers of the sprinkler and gages.

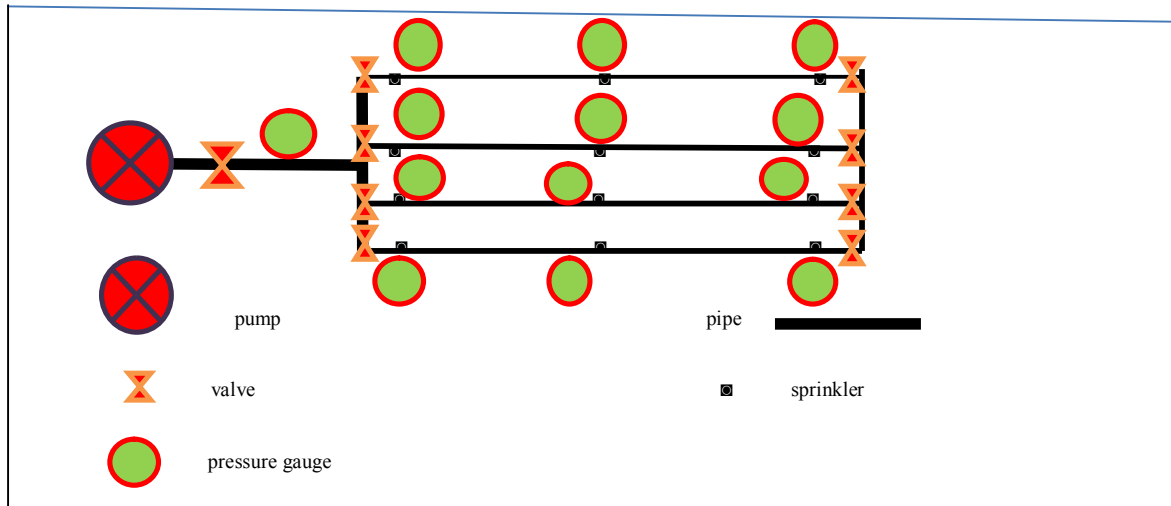


Fig. 1 The network at two cases

### 5-EPANET Software

EPANET is computer software that performs extended period simulation of hydraulic and water quality behavior within pressurized pipe networks. A network consists of pipes, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs. EPANET tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, and the concentration of chemical species throughout the network during a simulation period comprised of multiple time steps. In addition to chemical species, water age and source tracing can also be simulated. EPANET is designed to be a research tool for improving the understanding of the movement and fate of water constituents within distribution systems. It can be used for many different kinds of applications in distribution systems analysis: sampling program design, hydraulic model calibration, and chlorine residual analysis. EPANET software was applied on the network at two cases using the measured emitter flow rates and the total pressure in the field in order to show the pressure distribution in the network and then comparing the results of EPANET software with measured pressures in the network.

### 6- Analogue System:

Analogue techniques are potentially useful for data processing and for providing elements in instrumentation and control systems. The principle of studying a system indirectly by reference to an analogue system may be applied in a number of different ways. The relation between a system and its analogue is basically a mathematical one in which the set of equations that describes the interactions between various system variables is identical to the set of equations describing the interaction between corresponding variables in the analogue. The earliest analogue devices were based on

mechanical system, in which the analogue variables were the positions of the shafts. The movements of these shafts could be amplified or reduced (multiplied by constant) by the use of simple fixed gearing; two variables could be added or subtracted by means of differential gears; integration was achieved by a ball and wheel assembly. Different problems were solved by adjusting the mechanical layout of the analogue system so as to satisfy the appropriate set of equations, but perhaps acceptable for a special-purpose model of a particular system. It is also possible to build an analogue system based on hydraulic or pneumatic principles, and for some applications special-purpose analogue models of these kinds have proved to be useful (Wilkins, 1970).

### 6-1 Analogue Components:

The components of electrical analogue in the case study are depicted **Fig. 2** where the analogue system consists of:

1. Thermal wires (500 watts) to simulate the laterals where the power losses due to temperature in the thermal wires simulates the friction head losses in the laterals. And A power supply to simulate water supply.
2. A voltage regulator (1 volt) to simulate the valve in the main pipe used to regulate the discharge, An ammeter to simulate the pressure gages And Resistors (1 kilo ohm) to simulate the sprinklers.
3. Switches (on-off) at the ends of the lines of analogue to simulate the valves at the ends of the laterals (i.e. when switched off this state simulate traditional network and when switched on this state simulate looped network.

4. Equation  $q = ca\sqrt{2ch}$  ..... (11) simulates equation  $V=bI^y$  ..... (12)

Where:

- q: the discharge of sprinkler ( $L^3/T$ ) .
- a: cross section area of the sprinkler jet ( $L^2$ )
- h: the pressure at the sprinkler (L)
- c: discharge coefficient= 0.91
- V= Voltage in the resistor (volt),
- I= Current in the resistor (amper), and
- b, y = constants

The values of b and y may be found by any statistic program, and in this research, SPSS program has been used.

### 7-The Results and Discussion:

The practically results in different runs at two cases (looped and traditional network) in fixed sprinkler irrigation systems in fig 3 show that the average mean performance of the uniformity coefficients at looped fixed sprinkler irrigation system is (7.59%) and the theoretically results in different runs at two cases (looped and traditional network) in fixed sprinkler irrigation systems in fig 4 show that the average mean performance of the uniformity coefficients at looped fixed sprinkler irrigation system is (11.45%) in the looped network for the different runs, that mean the pressures distribution in the looped network is better than it in the traditional network. From above the looped network is the best.

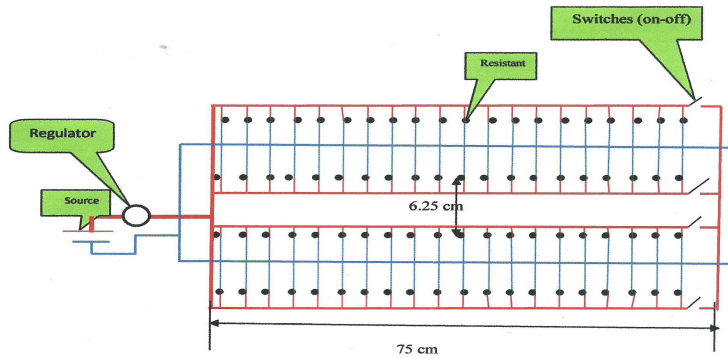


Fig. 2 The schematic analogue system

### 7-1 Analogue Results:

The switches are on when the system is on the proposed network (Fig.2), while these switches are off for the traditional network. The values of the constants in eq. (12) are: (b=10.774 and y=0.191) for traditional case and (b=5.912 and y=0.0157) for proposed case, which are computed through using SPSS program. Comparing eq.(11) below which is relative to the hydraulic performance of the sprinkler, with the eq. (12), which is relative to the electrical behavior in the analogue system, then the relative equation from the previous both equations is: Example for sprinkler at the two cases with  $q=0.000051h^{0.5}$

$V=10.774 I^{0.191}$  , When  $q=V$  as a value can be found the equation

$$h=rI^2 \dots \dots \dots (13)$$

$$h=384.47 \times 10^8 I^{0.382}$$

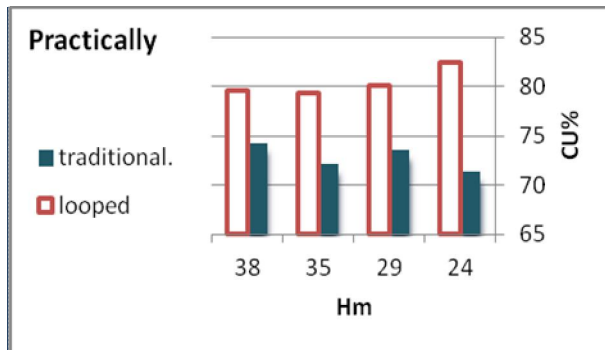


Fig. 3 The average mean performance of the uniformity coefficients at looped in theoretically case

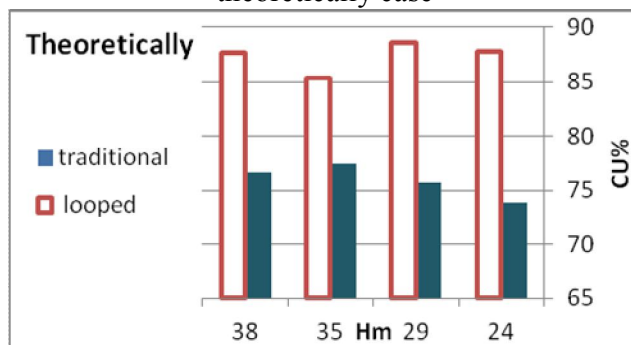


Fig. 4 The average mean performance of the uniformity coefficients practically case



## References

- Aarsalan FfarRyabi(2010): Evaluation of Uniformity Coefficients for Sprinkler Irrigation Systems under Different Field Conditions in Kurdistan Province (Northwest of Iran), *Soil & Water Res.*, 5, 2010 (4): 139–145.
- Al-Ghobari H.M. (2006): Effect of maintenance on the performance of sprinkler irrigation systems and irrigation water conservation. *Food Science & Agricultural Research Center, Research Bulletin*, 141: 1–16.
- Andre Daccache , N. Lamaddalena, U. Fratino(2010) "On-demand pressurized water distribution system impacts on sprinkler network design and performance" *Irrig Sci* (2010) 28:331–339 DOI 10.1007/s00271-009-0195-7.
- Anyoji H., Wu I. (1994): Normal distribution water application for drip irrigation schedules. *Transactions of the ASAE*, 37: 159–164.
- Beale J.G., Howell D.T. (1966): Relationship among sprinkler uniformity measures. *Journal of Irrigation and Drainage Engineering-ASCE*, 92: 41–48.
- Benami A., Hore F.R. (1964): A new irrigation sprinkler distribution coefficient. *Transactions of the ASAE*, 7: 157–158.
- Christiansen J.E. (1942): *Irrigation by Sprinkling*. California Agriculture Experiment Station Bulletin, No. 670.
- Criddle W.D., Davis S., Pair C.H., Shockley C.D. (1956): *Methods of Evaluating Irrigation Systems*. Agriculture Handbook No. 82, Soil Conservation Service, USDA, Washington, D.C.
- Dechmi F., Playan E., Faci J.M., Tejero M., Bercero A. (2003): Analysis of an irrigation district in northeastern Spain. II. Irrigation evaluation, simulation and scheduling. *Agricultural Water Management*, 61: 93–109.
- Hart W.E., Reynolds W.N. (1965): Analytical design of sprinkler systems. *Transactions of the ASAE*, 8: 83–89.
- Karmeli D. (1978): Estimating sprinkler distribution pattern using linear regression. *Transactions of the ASAE*, 21: 682–686.
- Keller J., Bliesner R.D. (1990): *Sprinkle and Trickle Irrigation*. AVI Book. Van Nostrand Reinhold, New York.
- Kincaid D.C., Solomon K.H., Oliphant J.C. (1996): Drop size distributions for irrigation sprinklers. *Transactions of the ASAE*, 39: 839–845.
- Li J. (1998): Modeling crop yield as affected by uniformity irrigation system. *Agricultural Water Management*, 38: 135–146.
- Magar SS, Mane MS, Shirke VS, Patil M (2007) Micro-irrigation strategies and perspective in India. *J. Water Manag* 15(2):107–113
- Mantovani E.C., Villalobos F.J., Orgaz F., Fereres E. (1995): Modelling the effects of sprinkler irrigation uniformity on crop yield. *Agricultural Water Mana-Management*, 27: 243–257.
- Merkley G.P. (2001): *Design Efficiency for Sprinkler Irrigation Systems*. Lecture Notes. Utah State University, Logan.
- Merriam J.L., Keller J. (1978): *Farm Irrigation System Evaluation: A Guide for Management*. Department of Agricultural and Irrigation Engineering, Utah State University, Logan.
- National Engineering Handbook (2005). "Sprinkle Irrigation" United States Department of Agriculture, Soil Conservation Service.

- Rodriguez Diaz JA, Camacho Poyato E, Lopez Luque R (2007) Model to forecast maximum flows( in on-demand irrigation distribution networks). *J Irrigation Drainage Eng* 133:3 (222).
- Solomon K. (1979): Variability of sprinkler coefficient of uniformity test results. *Transactions of the ASAE*, **22**: 1078–1086.
- Statistical Analysis System (SAS) (2003): *SAS User's Guide: Statistics*. Version 8.02, SAS Institute, Inc., Cary.
- Topak R., Suheri S., Ciftci N., Acar B. (2005): Performance evaluation of sprinkler irrigation in a semi-arid area. *Pakistan Journal of Biological Sciences*, **8**: 97–103.
- Wilcox J.C., Swailes G.E. (1947): Uniformity of water distribution by some under tree orchard sprinkler. *Journal of Scientific Agriculture*, **27**: 565–583.